5.—Alpha-activity of Western Australian soils and wheats

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Abstract

Lateritic soils formed on the Precambrian shield of south-western Australia have measured a-activities in the range 40-100 pCi/g from naturally occurring isotopes; whereas in soils formed on Mesozoic and Cainozoic coastal sediments the a-activity seldom exceeds 20 pCi/g.

The ash activity of wheat growing on the more active soils can be as high as 90 pCi/g. However, there is at least a three-fold variation in uptake of active isotopes depending on wheat variety.

For the lateritic soils there is a correlation between total a-activity and both ironstone gravel content and the total Fe + Al in the soil. There is also some evidence for an activity dependence on present climate and rainfall.

Although applied superphosphate fertilizer is high in natural radio-activity it is not believed to have made a significant contribution to the measured a-activity of the soil.

Introduction

The first measurements by Marsden (1961) of natural a-activity in Western Australian wheats and soils, from samples taken at Wongan Hills and Merredin, indicated unusually high levels of a-emitting isotopes when compared with samples taken elsewhere (Marsden, 1960; Mayneord, Turner and Radley, 1960; Zymlowska and Wilgain, 1961; Zymlowska and Ostrowdka, 1965).

From independent samples we have confirmed the high values reported by Marsden and have extended the range of observations to an additional thirty-five sites in the southern half of Western Australia.

Our interest in a-activity in Western Australian soils stems from two sources:

(1) the use of natural radio-activity as a tool for studying the absorption by plants of trace amounts of elements from soils. In particular it is expected that root exploration and the physical nature of the root/soil interface may be studied by following the absorption of certain nuclides.

(2) The measurements of isotopic ratios which may be used as indices of weathering (Talibudeen, 1964). The use of isotopic ratios is of particular interest, because large areas of Western Australia are characterised by well developed laterite profiles in which the dominant minerals are sesquioxides of iron and aluminium. It is known that thorium tends to accumulate with the sesquioxides (Talibudeen, 1964) and therefore, comparison of the Th/U ratio

in the laterites and their parent materials should provide a sensitive index of the weathering processes involved.

As a preliminary to these investigations however, it is necessary to measure total levels of a-activity and where possible correlate these levels with various plant and soil factors such as geological parent material, soil type, rainfall and leaching, clay mineral type and content, sesquioxide abundance, wheat variety and calcium content of soil and plant. The first results of this broad survey are presented in this paper.

Experimental Technique

Samples of topsoil and subsoil were collected from 35 sites in the south-west of Western Australia during July, 1966.

Included in these samples were soils from Wongan Hills and Merredin, two of the sites sampled by Marsden. The remaining localities were selected primarily for major differences in geological parent material and are shown in figure 1. Where fresh rock outcrops occurred near the site, they were also sampled.

If available, data was also recorded concerning superphosphate history and wheat variety.

Phosphate rock and superphosphate samples were collected from the two major distributors in Western Australia. Marsden (1959) has reported that phosphate rock is high in a-activity and because of the high rates of application of superphosphate on wheat growing soils in Western Australia it was necessary that the contribution from this source to the natural radio-activity should be determined.

Before measuring the a-activity levels, the soil and rock samples were dried in a 110° C oven and crushed to pass a 120 mesh sieve, and the separated wheat grain was ashed overnight at 600-650° C and again crushed to pass a 120 mesh sieve.

Particle size analyses were carried out on all the soil samples by screening through 10 mesh and 120 mesh sieves and the $< 2\mu$ clay fraction was separated by sedimentation. For a limited number of soil samples the a-activities of the gravel fraction, and the clay fraction were measured individually.

The detection and measurement of a-particles emitted from these powdered samples followed very closely the technique described in detail by Turner, Radley and Mayneord (1958). Basically, the sample was contained in a shallow translucent tray, one surface of which was coated with a finely divided scintillating phosphor. The powdered sample was in intimate contact with the phosphor and sealed into the tray to prevent loss of radon. A period of 3-4

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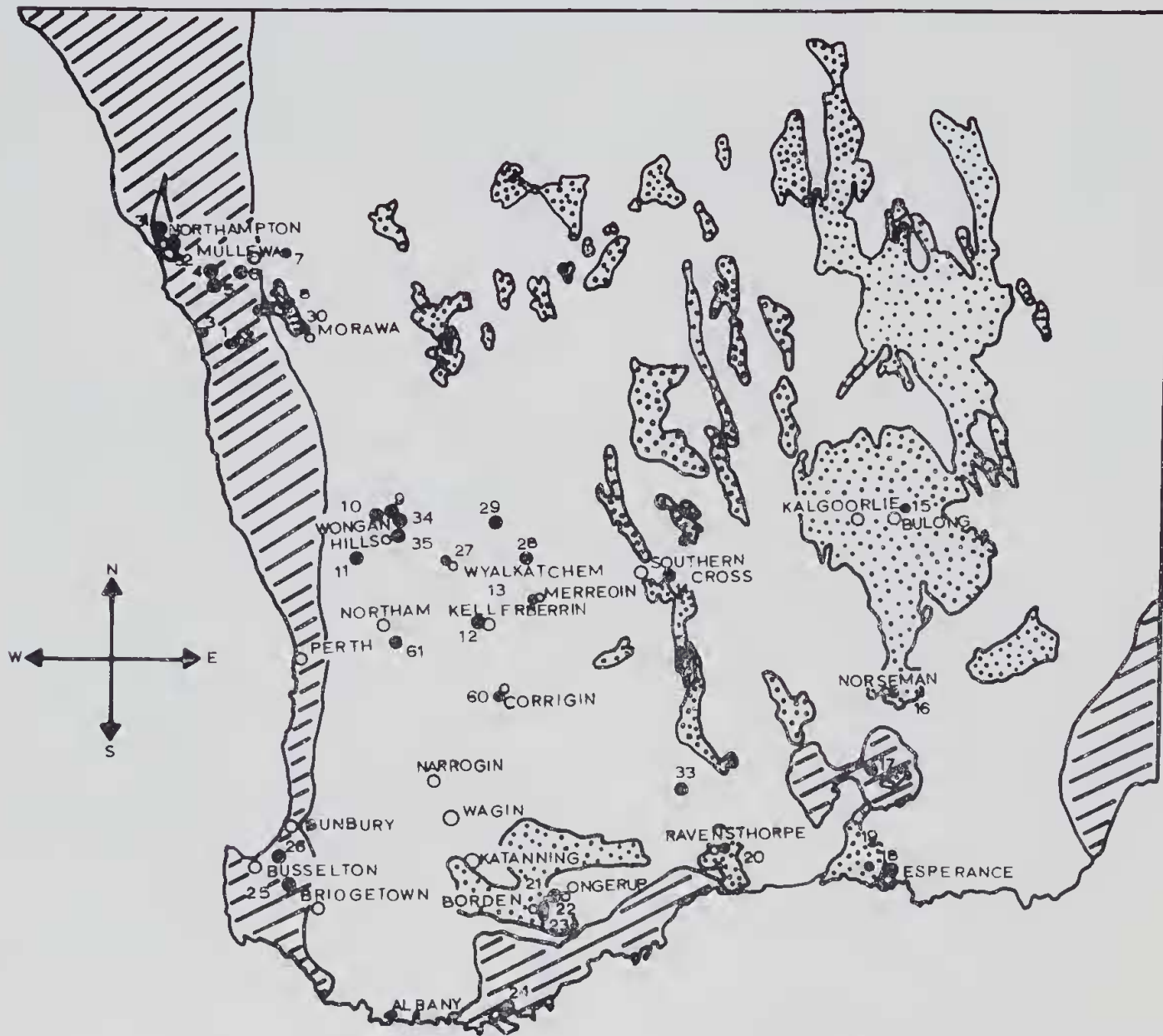
Figure 1.—Location of α-activity sampling sites in south-western Australia.

weeks was allowed to elapse before counting to allow radon and thoron daughters to reach equilibrium.

The scintillations from the phosphor were detected by a 5 in. photomultiplier and the resulting pulses, after amplification and discrimination were fed to a fast electronic scaler. Because the counting rates were comparatively low, dead-time losses were negligible.

In the thorium series disintegration chain, Rn^{220} emits an α-particle and decays to Po^{216} which again decays by α-emission to Pb^{212}. Since the half life of Po^{216} is 0.158 seconds, these successive emissions will be detected as pairs of α-particles with an average separation of approximately 0.2 seconds. For unweathered geological materials, where it can be assumed that the thorium series is in equilibrium, then the 'pairs' rate will give an accurate measure of the thorium concentration in the sample (Cherry, 1963). Further, for the thorium series in equilibrium the ratio of counts to pairs ($\frac{C}{P}$ ratio) as determined by Cherry (1963) is 16.4 and he has shown that an increase in the value of this ratio may be used to determine the concentration of uranium in the sample.

For soils or plant materials where weathering or preferential uptake of certain nuclides has disrupted the equilibrium of the thorium and uranium series it is not possible to measure thorium or uranium concentrations in this way. However, the thorium 'pairs' rate and $\dfrac{C}{P}$ ratio can still yield important information.

If for example, the $\dfrac{C}{P}$ ratio is significantly greater than 16.4 then either uranium is present in the sample, or there is a depletion of some of the daughter elements in the thorium series. The two possibilities may be distinguished by measuring those coincidence counts occurring in the time intervals 3.6 milli-seconds which are characteristic of the double α-decay of the isotopes Rn^{219}, and Po^{215} (half life 1.83 milli-seconds) of the uranium decay series.

If the $\dfrac{C}{P}$ ratio is significantly less than 16.4 this would indicate that the samples contain few, if any, of the head members of the thorium series.

In order to measure the uranium and thorium 'pairs' two fast mechanical registers and two co-incidence gates were interposed between the amplified pulse output and the electronic scaler. The mode of operation was as follows:—A pulse leaving the amplifier would be counted by the electronic scaler and would also activate the first coincidence gate for a period of 3.6 milli-seconds (two half-lives of Po^{215}). A second pulse arriving within this time interval would be recorded on both the electronic scaler and on the 'uranium pairs' register. After 3.6 milli-seconds the first coincidence gate would close and the second gate would open, remaining active for a period of 316 milli-seconds (two half lives of Po^{216}). A second pulse arriving within this time interval would be recorded by the electronic scaler (total counts) and on the 'thorium pairs' register.

Before the total α-activity and the thorium and uranium concentrations could be calculated, where applicable, it was necessary to know the mean atomic number $\bar{Z}$ (Turner, Radley and Mayneord, 1958) and mean atomic weight $\bar{W}$ (Cherry, 1963) of the sample material.

In the case of wheat ashes a combination of wet chemical and X-ray fluorescence analysis was used to obtain $\bar{Z}$ and $\bar{W}$, and for the parent rocks these values were calculated from published analyses of similar rock types (Mason, 1958).

For many Western Australian soils, major element analysis has shown that there is an excellent correlation between $\bar{Z}$ or $\bar{W}$ and the iron and calcium content of the soil. For these soils therefore, calcium and iron were measured by flame emission and absorption techniques respectively and the corresponding values of $\bar{Z}$ and $\bar{W}$ were determined.

Exchangeable calcium was measured using molar NH_4Cl to displace the calcium which was then determined on the S.P. 900 flame photometer.

The major clay and accessory minerals in the $< 2\mu$ fraction were analysed qualitatively using a Phillips X-ray powder diffractometer.

Full details of these analyses will be presented in a later publication.

Calculation of α-activity

The total α-activity in curies per gram (Ci/g) of each sample was calculated from the equation developed by Turner et. al. (1958), and is given by

$$A = \dfrac{C}{T} \cdot \dfrac{1}{R_0 . \overline{A.Z^{\frac{2}{3}}}} \cdot 9 \cdot 4 \times 10^{-11} \, \text{Ci/g} \qquad (1)$$

where C = counts/hour above background

R_0 = α-particle range in cm. of standard air.

A = area of sample in cm^2.

For unweathered rocks, in order to calculate the concentrations of uranium and thorium from the pairs counts it was necessary to allow for the chance occurrence of 'spurious pairs'.

This correction was carried out from the equation proposed by Cherry (1963) where the spurious pairs rate S is given by

$$S = C^2 . \tau \exp (- N_0.\tau) \qquad (2)$$

where again C = total count rate
and τ = dead time of the register circuit

The half life correction, as discussed by Cherry was applied to the corrected pairs rate to obtain a final value, P, for the pairs rate, in this case disintegrations occurring in two half lives were measured, yielding $\frac{3}{4}$ of the total 'pair' disintegrations, therefore the half life correction factor was 1.333.

Having determined the pairs rate P and the total α-count rate C (both in counts/hr) the thorium and uranium concentrations in p.p.m. for the rock samples were calculated from the equations

$$C = W^{\frac{1}{2}} . A (0 \cdot 155 \, U + 0 \cdot 0434 \, Th) \qquad (3)$$

$$P = W^{\frac{1}{2}} . A \left[\dfrac{Th}{378} \right] \qquad (4)$$

where A = area of sample

W = means atomic weight of sample

The derivation and limitations of equations (3) and (4) have been fully discussed by Cherry (1963).

For the soils and ashed wheats, as previously discussed, equations (3) and (4) do not apply and for these samples $\dfrac{C}{P}$ ratios have been calculated instead.

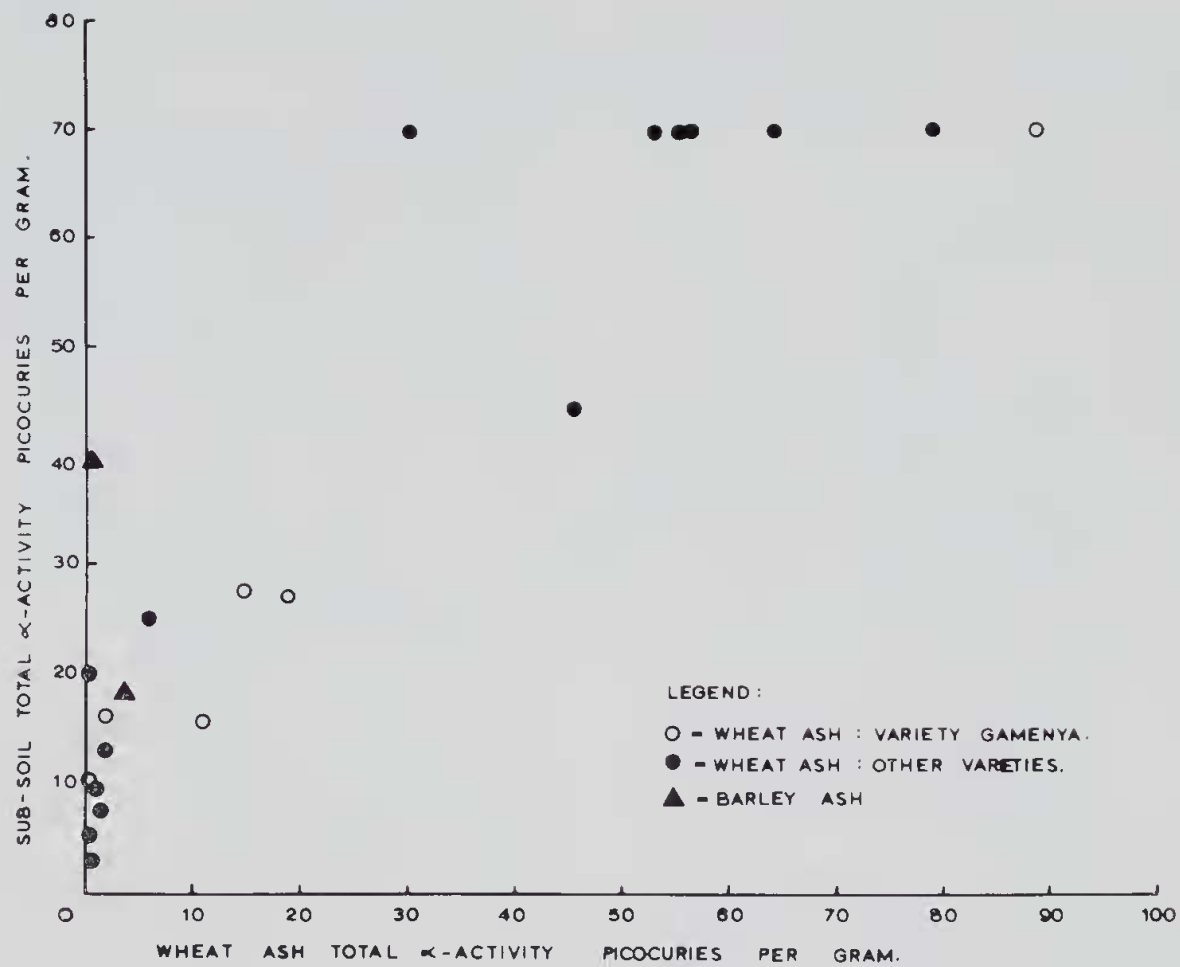Tables 1, 2 and 3 list these results for soil, ashed wheat and rocks respectively.

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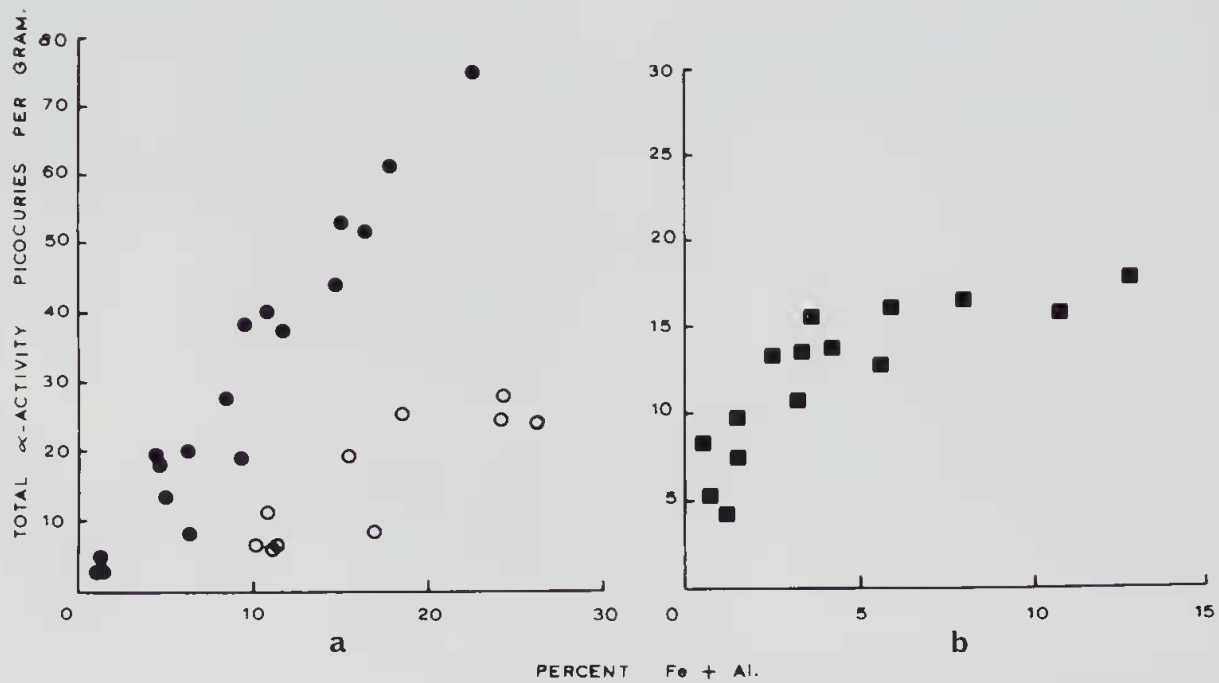
Figure 2.—Correlation of wheat-ash and soil α-activity.

Figure 3.—Correlation of soil α-activity with per cent. Fe + Al. 3a.—Total α-activity of soils formed on the Pre-Cambrian Shield of Western Australia; • = soils of lateritic origin; o = other soils. 3b.—Total α-activity of soils formed on Mesozoic and Cainozoic sediments.

Experimental results and discussion

From the data presented in Tables 1, 2 and 3 the following points were noted.

(i) Soils and wheats from the western part of the Precambrian shield were in general much more active than those from other localities measured in this survey, and elsewhere.

(ii) Although the ashed wheat activities were obviously dependent on the activity of the soil on which they were growing, Fig. 2, the correlation was much poorer than expected. This can be partially explained by the wide variation in uptake of α-emitting isotopes by wheats of different varieties as shown in Table 2 for site 10 at Wongan Hills. For these seven wheats, growing on the same soil there was a three-fold increase in the ash activity from the lowest to the highest respectively.

(iii) It has been stated that thorium tends to accumulate with sesquioxides of iron and aluminium (Talibudeen, 1964). Considerable difficulty was experienced in quantitatively extracting these sesquioxides from the soil samples and therefore a correlation was attempted between total α-activity and the sum of total iron and aluminium as measured on the atomic absorption spectrophotometer. The results are shown in Fig. 3. For those soils which are mainly of lateritic origin (closed circles Fig. 3a) there is a linear correlation, however in the second group (open circles Fig. 3a) the association between α-activity and percent Fe + Al is not as obvious. All the soils in this group are fine textured, therefore much of the aluminium will be present in the clay fraction rather than as sesquioxide. In addition, most of these soils contain finely divided fresh rock fragments and several were formed on or near basic dolerite

intrusions which would contribute to the high Al and Fe contents without a proportionate increase in total α-activity.

For the soils formed on Cainozoic and Mesozoic sediments the total α-activity is approximately proportional to the logarithm of the percent Fe + Al. This departure from linearity may be explained in a similar way, in that the more active soils contain a higher proportion of clay which in turn contains appreciable amounts of aluminium.

(iv) For soils formed on the Precambrian shield the α-activity levels of the sand and gravel components were often higher than the finer fractions as shown in Fig. 4a, where there is a definite negative correlation between total soil activity and percent soil passing a 120 mesh sieve. The soils formed on Cainozoic and Mesozoic sediments are by contrast low in α-activity and tend to exhibit a positive correlation with percent soil passing a 120 mesh sieve (Fig. 4b). Two soils from sites 18 and 19 (open circles Fig. 4a) do not fit this general scheme. Although formed on Precambrian granite rock and of coarse texture they are extremely low in α-activity. The soils at both of these sites have undergone severe leaching and consist mainly of coarse grains which apparently cannot retain active isotopes. For the five samples listed in Table 4 the gravel activity A_G was measured separately and the activity of the remainder of the sample A_R was calculated from the equation:

$$A_R = \frac{A_T - A_G \cdot x_G}{1 - x_G} \qquad (5)$$

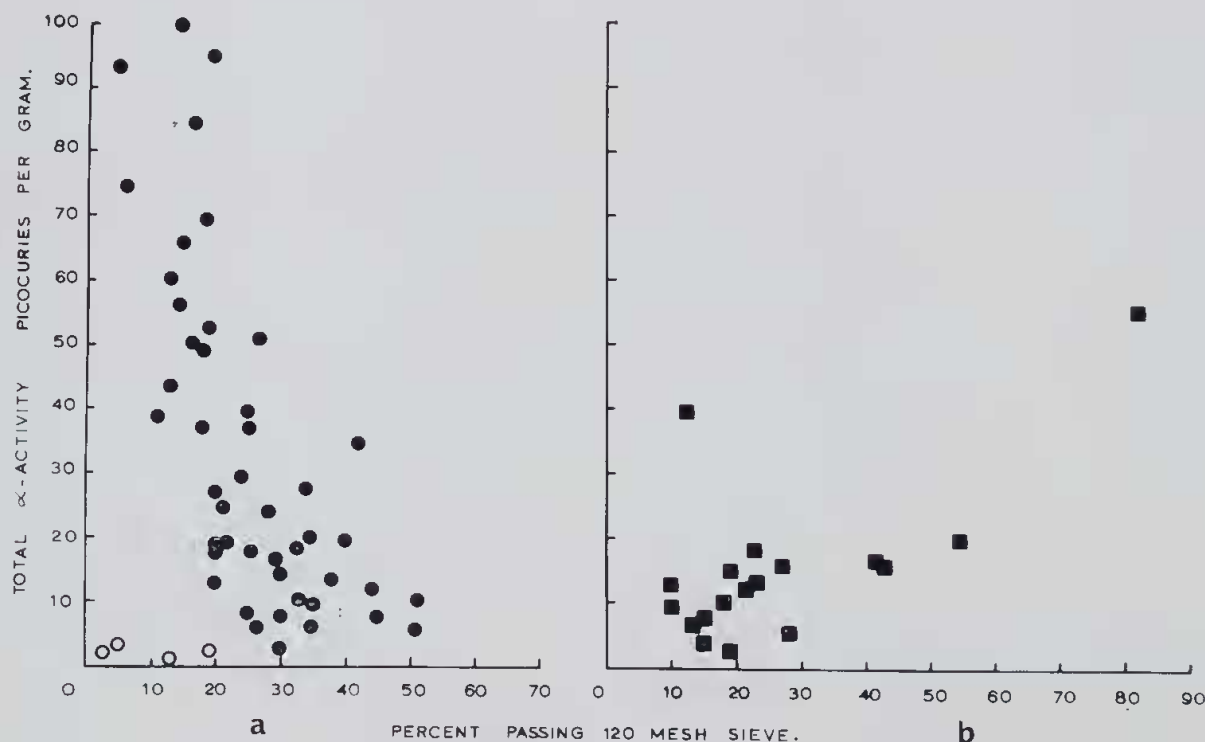where A_T = total activity of the sample x_G = weight fraction of gravel.

Figure 4.—Correlation of soil α-activity with particle size. 4a.—Total α-activity of soils formed on the Precambrian Shield of Western Australia; o = samples from sites 18 and 19. 4b.—Total α-activity of soils formed on Mesozoic Cainozoic sediments.

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TABLE 1

Table 1.—Total α-activity of surface and sub-soil samples.†

Site No. and Location	Sample No.	Depth Sampled	Gravel %	Geological Substrate	Total α – activity pCi/g	C/P	Munsell Colour
1. Irwin	1.1	0–12″	0	M.S.*	20	23	7.5 yr 4/2
2. Irwin	2.1	0–7″	0	M.S.	8	22	10 yr 4/1
	2.2	7–20″	0	M.S.	7	30	10 yr 6/3
3. Greenough	3.1	0–12″	0	M.S.	4	24	10 yr 3/3
	3.2	12–20″	1	M.S.	3	22	5 yr 6/3
4. Eradu	4.1	0–5″	0	M.S.	11	20	2.5 yr 4/4
	4.2	5–15″	0	M.S.	16	34	2.5 yr 5/6
	4.3	15–20″	0	M.S.	13	20	2.5 yr 5/6
5. Eradu	5.1	0–4″	0	M.S.	10	24	10 yr 6/2
	5.2	4–20″	0	M.S.	13	20	7.5 yr 6/6
6. Tenindewa	6.1	0–6″	3	M.S.	16	26	2.5 yr 3/6
	6.2	6–24″	4	M.S.	16	17	2.5 yr 3/8
7. Pindar	7.1	0–6″	10	A.G.	27	33	10 yr 6/4
	7.2	6–20″	66	A.G.	75	29	10 yr 7/6
	7.2.5**	6–20″	....	A.G.	81	17	
8. Canna	8.1	0–4″	8	A.S.	19	16	5 yr 4/6
	8.2	4–16″	29	A.S.	25	20	2.5 yr 3/6
	8.2.5	4–16″	....	A.S.	40	16	
9. Wongan Hills	9.1	0–4″	0	A.G.	19	22	2.5 yr 6/2
Sampled Aug. '66	9.2	4–12″	8	A.G.	19	20	2.5 yr 7/4
	9.3	12–17″	41	A.G.	37	28	
	9.4.3	12–17″	....	A.G.	45	19	
Sampled Nov. '66	9.6	0–4″	....	A.G.	18	26	
	9.7	4–12″	....	A.G.	20	26	
	9.8	12–17″	....	A.G.	34	20	
	9.9	0–4″	....	A.G.	55	....	
Sampled Nov. '65	9.10	4–8″	....	A.G.	34	....	
10. Wongan Hills	10.1	0–5″	16	A.G.	66	20	10 yr 7/2
	10.2	4–10″	20	A.G.	70	16	
	10.2.2	4–10″	....	A.G.	66	24	
	10.2.5	4–10″	....	A.G.	83	16	
	10.3	10–20″	47	A.G.	60	29	2.5 yr 5/6
	10.4	0–4″	....	A.G.	85	12	
	10.5	4–8″	....	A.G.	95	15	
	10.6.5	Surface Gravel	....	A.G.	172	15	
11. Calingiri	11.1	0–4″	45	Dolerite Dyke	29	26	2.5 yr 5/4
	11.1.5	0–4″	.	Dolerite Dyke	33	15	
	11.2	4–15″	20	Dolerite Dyke	28	28	2.5 yr 5/6
11. Calingiri	11.3	15–22″	17	Dolerite Dyke	25	30	2.5 yr 3/6
12. Kellerberrin	12.1	0–4″	5	A.G.	18	15	10 yr 5/1
	12.2	6–14″	56	A.G.	44	17	2.5 yr 7/2
	12.2.5	6–14″	....	A.G.	53	17	
	12.3	14–28″	3.5	A.G.	51	27	10 yr 7/6
13. Merredin	13.1	0–3″	1	A.G.	49	16	7.5 yr 5/4
	13.2	3–14″	8	A.G.	52	16	5 yr 5/4
14. Southern Cross	14.1	0–8″	0	A.G.	37	14	2.5 yr 4/4
	14.2	8–27″	8	A.G.	40	17	5 yr 5/8
15. Bulong	15.1	0–10″	27	A.S.	6	17	5 yr 6/3
	15.2	10–20″	32	A.S.	3	13	5 yr 6/4
16. Norseman	16.1	0–2″	16	A.S.	8	17	7.5 yr 5/4
	16.2	2–10″	25	A.S.	8	36	7.5 yr 6/4
	16.3	10–22″	8	A.S.	11	28	5 yr 5/3
17. Dowak	17.1	0–3″	0	M.S.*	14	21	7.5 yr 5/4
	17.2	3–20″	10	M.S.	14	21	
18. Esperance	18.1	0–24″	0	A.G.	3	27	5 yr 8/4
	18.2	24–48″	0	A.G.	4	18	2.5 yr 8/6
	18.3	48–60″	21	A.G.	39	17	10 yr 5/6
19. Dalyup	19.1	0–8″	0	A.S.	2	20	2.5 yr 6/2
	19.2	8–30″	0	A.S.	2	21	2.5 yr 8/2
20. Ravensthorpe	20.1	0–5″	53	A.S.	8	20	5 yr 5/3
	20.2	5–12″	6	A.S.	10	18	5 yr 5/6
21. Ongerup	21.1	0–4″	0	A.G.	13	14	10 yr 5/1
22. Borden	22.1	0–6″	0	A.S.	5	18	5 yr 5/3
	22.2	6–14″	0	A.S.	5	20	10 yr 7/3
	22.3	14–24″	0	A.S.	12	10	2.5 yr 4/6
23. Borden	23.1	0–3″	9	A.S.	6	22	5 yr 3/4
	23.2	3–12″	2	A.S.	11	13	2.5 yr 3/4
	23.3	12–16″	2	A.S.	6	12	7.5 yr 7/6
24. Albany	24.1	0–4″	44	M.S.	17	22	10 yr 5/1
	24.2	4–16″	76	M.S.	40	17	10 yr 7/3
	24.2.5	4–16″	....	M.S.	30	23	

* M.S. = Mesozoic and Cainozoic marine sediments.
  A.S. = Archaean Sediments with basic igneous intrusives.
  A.G. = Archaean granite.
** Sample number with two digits only, were prepared by grinding to pass a 120 mesh sieve.

Third digit = 2 < 2μ fraction.

               3 mottles separated and ground.

               5 gravel separated and ground.

† The exact locations of the above samples sites are available from the authors.

TABLE 1 (Continued)

Table 1.—Total α-activity of surface and sub-soil samples.†

Site No. and Location	Sample No.	Depth Sampled	Gravel %	Geological Substrate	Total α – activity pCi/g	$\frac{C}{P}$	Munsell Colour
	24.3	16–26″	16	M.S.	57	27	10 yr 6/6
25. Jarrahwood	25.1	0–6″	0	M.S.	5	22	10 yr 7/1
	25.2	6–15″	17	M.S.	14	17	2.5 yr 7/2
	25.3	15–30″	53	M.S.	18	67	
26. Capel	26.1	0–24″	....	M.S.	52	...	
34. Wongan Hills	34.1	0–4″	0	A.G.	51	7	
	34.2	4–8″	0	A.G.	17	21	
	34.3	8–16″	43	A.G.	49	17	
35. Wongan Hills	35.1	0–4″	47	A.G.	56	17	
	35.2	4–8″	79	A.G.	94	29	
60. Corrigin	60.1	0–3″	42	A.G.	101	....	
61. Corrigin	61.1	20–24″	65	A.G.	282	....	
62. York	62.1	0–2″	....	A.G.	39	....	
	62.2	2–8″	....	A.G.	46	....	

† The exact locations of the above samples sites are available from the authors.

The last column of Table 4 lists the ratio $\frac{A_G}{A_R}$, from which it can be seen that the gravel fraction was generally higher in activity than the remainder. Sample 24.2 was an exception; however in this sample the coarse material mainly consisted of rounded pieces of magnetic haematite, in contrast to the concretionary ironstone gravels in the other samples.

For these ironstone gravels the uranium pairs count rate was negligible and the $\frac{C}{P}$ ratios were in the range 15-17 which is characteristic of the Th^{232} decay series in equilibrium. Some caution must be exercised in interpreting these $\frac{C}{P}$ ratios however, because recent experiments, using a new counting technique to determine true pairs directly, indicate that the Poisson distribution used by Cherry (1963) over estimates the spurious pairs at high count rates. Further work is required before a better correction can be established with any degree of precision.

(v) The contribution from superphosphate application to the total α-activity of a soil was estimated from measurements of the activity of eight batches of superphosphate produced by CS-BP and CRESCO, the two leading distributors in Western Australia (Table 3). A mean for the superphosphate activity was 63 pCi/g and for a typical application rate (180 lbs/acre) the increase in soil activity at the surface would be 30 pCi/sampling area (250 cm²). If, for example, as the result of ploughing or leaching, this activity was distributed through only the top 10 cm of soil, then the increase in soil activity would be of the order 0.01 pCi/g. The general conclusion may be reached then, that even prolonged applications of superphosphate fertiliser at high rates will not cause a measurable increase in soil α-activity.

At Wongan Hills, sites 9 and 10, a comparison of soils which had received heavy applications of superphosphate (samples 9.1, 9.2, 9.3, 10.1, 10.2, 10.3) and of the same soils which had received no superphosphate (samples 9.6, 9.7, 9.8, 10.4, 10.5) showed the activity levels to be comparable or even higher in the unsupered soils, thus supporting this general conclusion. A possible exception was encountered at site 11, Calingiri, where a shallow clay-loam soil has developed directly on a dolerite dyke. In this soil, activity levels of approximately 30 pCi/g were encountered whereas the activity of the

TABLE 2

Table 2.—Total α-activity of ashed wheat and barley.

Site No. and Location	Wheat Variety	Total α–activity pCi/g	$\frac{C}{P}$
1. Irwin		<1	23
2. Irwin	... .	2	30
3. Greenough	....	1	19
4. Eradu	Bungulla *Gamenya	11	59
5. Eradu	Insignia	2	23
6. Tenindewa .	Gamenya	2	21
7. Pindar	Gamenya	19	27
8. Canna . ..	..	6	42
10. Wongan Hills ..	Falcon	65	...
Wongan Hills ..	Gamenya ..	90	18
Wongan Hills	Gabo	80	17
Wongan Hills	Beucubbin .	56	34
Wongan Hills ..	Noongar ..	31	46
Wongan Hills	Insignia	55	34
Wongan Hills	Wagin	54	17
11. Calingiri	Gamenya	15	61
12. Kellerberrin .. .	....	46	57
20. Ravensthorpe	....	1	23
21. Ongerup	*	4	32
22. Borden	....	<1	9
23. Borden	Gamenya	<1	9
24. Albany . .	* . .	<1	20
27. Wyalkatchem ..	Gabo	8	22
28. Nungarin	Insignia .	2	43
27. Benenbbin	. .	4	33
30. Morawa ..	Falcon	2	14
31. Northampton .. .	Mengarvie ...	1	21
32. Northampton ..	Gamenya ...	<1	23
33. Lake King ..	....	9	33
60. Corrigin	....	69	...

* Barley Ash.

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TABLE 3

Table 3.—Total α-activity of rocks and superphosphate.

Site, Location or Source	Sample	Total α activity pCi/g	C P	U ppm	Th ppm
9. Wongan Hills	Archaean Granite	65	34	12	40
11. Calingiri ..	Dolerite	4	24	<1	3
16. Norseman ...	Archaean Gneiss	7	40	<1	4
18. Esperance	Proterozoic Granite	59	21	4	60
24. Albany	Limestone	20	15	0	29
Senegal .	Phosphate Rock	218	42	...	...
Florida	Phosphate Rock	348	23	....	....
Nauru Island	Phosphate Rock	191	...	....	....
Togoland	Phosphate Rock	252	....	....	...
Ocean Island	Phosphate Rock	184	....	....	...
Xmas Island	Phosphate Rock	47	....	....	.
Cresco, Perth	Superphosphate '65-'66	59	35	....	....
Cresco, Perth	Nov. '66	74	66	....	....
Cresco, Perth	Feb. '62	51	50	....	....
CSBP, Esperance	'65 '66	55	31	....	....
CSBP, Albany	'65-'66	66	33	....	....
CSBP, Perth	'63-'64	71	26	...	....
CSBP, Perth	'64-'65	72	34	....	....
CSBP, Perth	'65 '66	54	24	...	....

parent dolerite was only 4 pCi/g. Here it would seem that one or more components in the soil has the ability to 'fix' α-active isotopes from the applied superphosphate.

The increasing use of highly active Florida rock phosphate in Western Australian superphosphates from 1966-67 onwards may clarify this situation for subsequent samplings.

(vi) at site 9, Wongan Hills, a series of soil measurements at yearly intervals since 1965 has indicated that the rate of movement of α-active isotopes through the soil profile may be much faster than is generally supposed. Topsoil and subsoil taken late in 1965 whilst the site was in crop were quite active, 55 pCi/g and 34 pCi/g for the 0-4 in. and 4-8 in. sample respectively (samples 9.9 and 9.10) which are comparable with values measured by Marsden (private communication). After lying fallow for a year the

TABLE 4

Table 4.—Comparison of total α-activity of the whole soil with that of the gravel component.

Sample	Weight Fraction Gravel x g	Total Activity A T (pCi/g)	Gravel Activity A G (pCi/g)	Remainder Activity A R	$\dfrac{A_G}{A_R}$
7.2	0.66	81	83	78	1.1
8.2	0.29	27	41	22	1.9
10.2	0.35	71	86	63	1.4
12.2	0.56	45	54	33	1.7
24.2	0.78	43	33	78	0.4

site was re-sampled in 1966 and again in 1967. For these samples (9.1, 9.2, 9.3) there was a significant decrease in surface activity. However, at a depth which coincided with a zone of soft iron concretions and clay mottlings the activity was again quite high. The inference then, is that ploughing throws active materials into the surface soil and this subsequently leaches back to the sesquioxide horizon. Further detailed sampling will be required to confirm this point.

(vii) From the measurements of α-activity made so far, it is difficult to make conclusive statements regarding the effects of climate and rainfall, however, the following observations appear to be pertinent.

On an easterly transect through York, Kellerberrin, Merredin and Southern Cross to Bulong and Norseman there is a steady decrease in mean rainfall from 18-20 in. to 9-10 in. Eastwards as far as Merredin, which lies close to the 12 in. isohyet, the dominant soils are coarse textured yellowish loamy sands with much ironstone gravel, and the soil α-activity is reasonably constant in the range 45-50 pCi/g.

Further eastwards the activity diminishes sharply to 2-10 pCi/g (Bulong and Norseman) and the soil becomes a finer textured gravel-free reddish clay-loam with a much more uniform distribution of iron through the profile. Therefore it would appear from the present results that when the mean annual rainfall is sufficient to cause waterlogging in winter and favour gravel formation then there is also a concentration of α-active isotopes.

Further south, at Esperance and Dalyup in the 25 in. rainfall belt. with a more uniform distribution of rainfall throughout the year the soils are more severely leached, contain negligible amounts of Fe and Al and are extremely low in activity.

Conclusions

Lateritic soils formed on the Precambrian shield of Western Australia are unusually high in natural α-activity and there is a definite association between activity levels and the ironstone gravel content of the soils. For these soils there is also a significant correlation between activity and Fe $+$ Al content.

Some of the active isotopes present in the soil are readily taken up by wheat, however the rate of uptake varies widely with variety.

Although superphosphate fertiliser is high in natural α-activity it is unlikely at normal application rates to have made a significant contribution to the total soil activity.

There is some evidence that leaching of active isotopes through the soil profile may be quite rapid in regions of adequate rainfall and there appears to be an association between soil activity levels and rainfall and climate.

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